NASA/CR-1998-207678

Key Metrics and Goals for NASA's Advanced Air Transportation Technologies Program

Bruce Kaplan and David Leee
Logistics Management Institute, McLean, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Contract NAS2-14361

May 1998

Available from the following:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 487-4650

Contents

FIGURES

TABLES

Chapter 1
Introduction and Summary

NASA's Advanced Air Transportation Technologies (AATT) program is developing a set of decision support tools to aid air traffic service providers, pilots, and airline operations centers in improving operations of the National Airspace System (NAS). NASA will develop each DST with high potential benefits to the point that the basic technology is proven. At that point, the Federal Aviation Administration (FAA) will evaluate the tool for potential full-scale development and deployment throughout the NAS.

A variety of efforts already underway were consolidated under the AATT umbrella. The AATT program plans to initiate new projects as well. The research efforts focus on improving operations in three areas:

- At airports and their vicinity (terminal area) during takeoff and climb and approach and landing,
- En-route at FAA air traffic management facilities and in the cockpit, and
- On the ground at airports.

These efforts range in maturity from concept to demonstrated technology, ready to be implemented by the FAA. Table 1-1 shows the AATT products included in this study.

Other tools also are planned for future development but were not sufficiently documented for inclusion in this study. For more information, see the *Summary Overview and Status of AATT Program Development Activities* (ref 1) and *AATT Program Operation Concept* (ref 2).

NASA needs a set of unifying metrics to tie these efforts together, which it can use to track the progress of the AATT program and communicate program objectives and status within NASA and to stakeholders in the NAS. These stakeholders include the airlines, other airspace users, aircraft manufacturers, the FAA, air traffic controllers, Congress, and the traveling public. Furthermore, a concise set of metrics will help AATT program managers to compare AATT products, their status, and priority relative to the others.

Table 1-1. AATT Products Included in Study

AATT product	Description
Terminal area operations:	
Traffic Management Advisor (TMA)	Decision support tool (DST) to assist air traffic controllers (ATC) in metering traffic into terminal airspace
Passive Final Approach Spacing Tool (P-FAST)	DST to generate advisories to ATC on arrival schedule, sequencing, and runway assignment
Active Final Approach Spacing Tool (A-FAST)	DST to generate flight path advisories to ATC for each arriving aircraft
Expedite Departure Path (EDP)	DST(s) to assist ATC in load management, sequencing, spacing, and merging departing traffic into en-route traffic streams
En route operations:	
Conflict Prediction and Trial Planner (CPTP)	DST to identify potential conflicts and evaluate trial resolutions in advance of current ATC time horizon
Airspace Tool and Sector Tool (AT/ST)	Paired DSTs to support ATC conflict prediction and resolution in low traffic, unconstrained regions (AT) and high-traffic, or otherwise constrained areas (ST)
Advanced En-route Ground Automation (AERGA)	DST(s) to support ATC, airlines, and air crew in meeting scheduled arrival in the terminal area, automatic conflict resolution, data exchange between ATC sites and between ATC and aircraft, and automated trajectory negotiation
Collaborative Arrival Planning (CAP)	DST to support data exchange, communication, and planning between ATC and airlines
Enhanced Cockpit Display of Traffic Information (E-CDTI)	DST to support air crew situation awareness of traffic, conflict detection and avoidance, and trajectory negotiation with ATC
Airborne Integrated Route Planner for Avoiding Traffic and Hazards (APATH)	DST to support air crew situational awareness of traffic and other hazards with a longer time horizon than CDTI and to plan routes to avoid those conflicts and hazards
Airport ground operations:	
Passive Surface Movement Advisor (SMA-1)	DST to share information among air traffic controllers, airport operators, and airlines
Active Surface Movement Advisor (SMA-2)	DST(s) to extend the information content and airport applicability of SMA-1

Source: *Summary Overview and Status of AATT Program Development Activities* (ref 1).

The LMI task was to provide such a set of metrics and to determine reasonable goals that the AATT program should strive to achieve for each. This report documents the results of our efforts and the four unifying metrics we recommend for the AATT program. They are as follows:

- Improve *airport peak capacity* by 30 to 40 percent—in terms of operations per hour as measured in a 15-minute interval; this metric applies to airport terminal area operations.
- Increase *en-route sector capacity* by 10 to 20 percent—in terms of the number of aircraft a controller can safely handle at one time; this metric applies to en route operations.

- Reduce *block time and fuel* 2 to 5 percent and 2 to 4 percent respectively—in terms of the time and fuel necessary to fly a set of routes with particular aircraft under similar conditions. This metric applies to airport terminal area, en-route, and ground operations. That is to say, it applies to all AATT products.

- *Enable free flight* by conducting expert evaluation of AATT program's progress toward providing free flight-enabling technologies;[1] this metric applies to en route operations.

The first three metrics are objective, observable measures. The last is subjective. Together, these metrics provide full coverage for all AATT products and objectives.

APPROACH

We define metrics as measurable quantitative or qualitative properties that can be improved, maintained, or reduced. The approach followed to develop metrics for the AATT program was to first survey airspace metrics previously proposed for the AATT program and those in use or proposed by NASA headquarters, the FAA, and others for measuring performance of the NAS. We then grouped the metrics into related topics and evaluated each against the desired attributes of relevance to AATT products, measurability, time, and cost to measure, availability of baseline measurements, and relevance to the FAA and airspace users.

We found that the metrics proposed varied from broad, far-reaching ones, such as those implicit in NASA's "Global Civil Aviation Goals" (see Figure 1-1) to the very detailed, such as delays caused by system outages (ref 4).

We found broad and detailed metrics in each of these categories.

Figure 1-1. NASA's Global Civil Aviation Goals

- Reduce accident rate by a factor of five in 10 years and a factor of 10 in 20 years.
- Reduce emissions by a factor of three in 10 years and a factor of five in 20 years.
- Reduce perceived noise of future aircraft by a factor of two in 10 years and a factor of four in 20 years.
- While maintaining safety, triple aviation system throughput in all weather conditions within 10 years.
- Reduce the cost of air travel by 25 percent within 10 years and 50 percent within 20 years.

[1] Free flight is the concept endorsed by the FAA and airspace users that would enable users to determine their own flight trajectories to the maximum extent possible (ref 3).

In general, metrics with potential applicability to the AATT program fell into seven categories:

- Capacity
- Flexibility
- Efficiency
- Predictability
- Safety
- Environment
- Delay.

Because the AATT program conducts research and development, its impacts on the NAS will be realized in the future. Actual *measurement* of AATT impacts can occur only during testing, primarily human-in-the-loop and field testing. Even then, field testing may not show the full impact of AATT products if implementing those products requires changes in FAA or airline policies and procedures, such as flight planning and route approval, of broader geographic coverage than the test area. For these reasons, the metrics selected must be able to predict impact on the NAS based on less than global measurement and analysis.

In the course of discussions with the AATT program office, it became apparent that what was needed was not a grocery list of measures with applicability to specific products, but rather, a short list of unifying metrics with applicability to multiple products to tie the products together, set priorities, and communicate program goals both within the AATT program and externally to NASA headquarters and NAS stakeholders. The need identified was to develop a limited, high-level set of metrics to establish program goals, set priorities, and communicate externally and within the program.

This need for high-level metrics eliminated many of the more detailed metrics from consideration for the overall program, although many of these will need to be addressed by individual products. Additionally, it focused attention on developing AATT objectives and metrics to reflect those goals.

The four metrics we introduced earlier are the results of those discussions. In the next chapter, we describe each in more detail.

The final step of the study was to develop objectives for each of the recommended metrics. For the three quantitative metrics, this was accomplished in conjunction with another AATT-sponsored study addressing program analysis and product

prioritization. The goal for the qualitative measure is less specific since no baseline data exist.

ORGANIZATION OF THIS REPORT

This report recommends four key metrics for use by the AATT program. Chapter 2 defines these in more detail and identifies how to measure each and model its impact. Chapter 3 provides estimates of the program's potential impact along with a supporting rationale. Chapter 4 provides a strategy to track the metrics and develop detailed product analysis plans. Chapter 5 summarizes our findings and presents our conclusion and recommendations.

Chapter 2

Key Advanced Air Transportation Technologies Program Metrics (AATT)

In this chapter, we discuss each of the four metrics we propose, defining each and identifying how it should be measured and/or modeled over the course of the Advanced AATT program.

AIRPORT PEAK CAPACITY

Congestion at airports is the single biggest cause of delay in the NAS. When demand for service at one major airport and the surrounding air traffic control sectors exceeds capacity, delays can spread throughout the nation as airplanes are held on the ground. This creates costs for airspace users and travelers. If the problems are systemic, airlines build expected delays into their schedules, increasing their costs for fuel and labor and providing less service with a given fleet of aircraft.

Today, aircraft using the nation's airports experience arrival delays averaging over 7 minutes per flight. At the busiest airports, average arrival delay can exceed 10 minutes (see Table 2-1). This is based on the Department of Transportation's (DOT) Airline Service Quality Performance Data (ASQP), which is based on airline schedules that already include some time for expected delays. In the future, delays are expected to grow as air traffic increases (references 4 and 5).

Improving airport capacity is a major goal of the AATT program. Many of its products will help reduce congestion at airports by utilizing facilities more efficiently. A metric is needed to show the program's impact. The one we recommend is *airport peak capacity.*

The AATT products with the greatest impact on airport capacity are those addressing terminal area operations:

- Traffic Management Advisor (TMA)
- Passive Final Approach Spacing Tool (P-FAST)
- Active Final Approach Spacing Tool (A-FAST)
- Surface Movement Advisor (SMA)
- Expedite Departure Path (EDP).

Additionally, Advanced En-route Ground Automation has the potential to improve airport capacity, although to a lesser extent.

Table 2-1. Airport Arrival Delays

Airport code	Airport	ASQP arrivals	Avg. arrival delay (min.)
LAX	Los Angeles Int., CA	175,844	10.30
SFO	San Francisco Int., CA	126,150	10.02
ATL	Hartsfield Int., GA	226,990	8.95
BOS	Logan Int. Airport, MA	89,769	8.88
STL	Lambert Int., MO	170,215	8.41
SEA	Seattle/Tacoma Int., WA	90,805	8.36
EWR	Newark Airport, NJ	105,911	8.10
MIA	Miami Int. Airport, FL	69,557	8.08
SLC	Salt Lake City, UT	83,238	8.01
MCO	Orlando Int., FL	67,186	7.96
LAS	McCarran Int., NV	110,926	7.90
PHX	Sky Harbor Int., AZ	154,915	7.71
SAN	Lindberg Field, CA	64,777	7.71
BWI	Baltimore-Washington Int., MD	65,444	7.14
OAK	Metropolitan Oakland, CA	64,525	6.88
ORD	O'Hare Int. Airport, IL	286,050	6.32
IAH	Houston Int., TX	119,149	6.14
DEN	Stapleton Int., CO	128,687	5.93
PHL	Philadelphia Int., PA	89,809	5.91
CLT	Charlotte, NC	129,243	5.57
DCA	National Airport, DC	83,694	5.49
PIT	Greater Pittsburgh, PA	123,414	5.39
LGA	La Guardia, NY	96,637	5.27
DFW	Dallas/Ft. Worth Int., TX	262,718	5.08
DTW	Wayne County Airport, MI	143,315	4.97
MSP	St. Paul Int., MN	132,416	3.91

Source: 1995 ASQP

Definition

Airport peak capacity is the total number of operations, departures and arrivals, per hour as measured in a 15-minute interval and multiplied by four. The interval chosen should be one where demand exceeds capacity.

Because improvements in capacity have an effect only when demand for service nears capacity and are most pronounced when demand exceeds capacity, it is necessary to count operations for this metric during a peak period. At major airports, particularly hubs, these peaks periods occur many times each day. Their durations vary, but they typically last less than an hour. The 15-minute period was chosen because it is long enough to smooth minor fluctuations but still shorter than these

peak periods, sometimes called rushes, banks, or complexes. The 15-minute interval has the added advantage of already being in use at some FAA facilities (those with CTAS) and by some airlines (those which use the passive surveillance radar [PASSUR] system). Measurement should occur during the true peak, not its tails, in order to assess AATT product impact fully. This will likely mean that the measurement interval of 15 minutes will not align with the hour, half-hour, or quarter-hours.

Measurement and Modeling

Counting operations at an airport during testing is very straightforward. However, data today are not very easy to obtain since flight track data usually end or begin well off the end of the runway and may not match up aircraft with runways, flight numbers, or actual takeoff/touchdown times. The FAA has efforts underway to improve these data.

Prior to testing, models such as the Airport Capacity Models (references 6,7, and 8) can be used to estimate the impact of products on individual airports. These models were developed for NASA's Terminal Area Productivity Program. It should be noted that since the configuration and weather at each major airport is different, the impact of a particular technology on a given airport must be individually estimated.

Data sources on airport operations to establish baselines and conduct tests of airport capacity include

- Enhanced Traffic Management System (ETMS),
- ARINC Communications Addressing and Reporting System (ACARS), and
- Passive Surveillance Radar (PASSUR).

These systems may not provide all necessary data (e.g., which runway was used) and, therefore, will need to be supplemented with data collected specifically for the test or baseline.

Care should be taken to evaluate data for peak periods only.

EN-ROUTE SECTOR CAPACITY

Many of the AATT products are designed to either prevent potential conflicts (aircraft approaching too closely) or to reduce the burden on the air traffic controller of managing a given amount of traffic in a given sector of airspace. Each of these has the potential to increase the number of aircraft a single controller can handle at one time. This leads us to the *en-route sector capacity* metric.

The products with the greatest impact on en-route sector capacity are

- Conflict Prediction and Trial Planning (CPTP),
- Airspace Tool and Sector Tool (AT/ST),
- AERGA, and
- Enhanced Cockpit Display of Traffic Information (E-CDTI)

Definition

En-route sector capacity is the maximum number of aircraft a controller can handle at one time for a sustained period.

Today, that number is 18, plus or minus 3 aircraft (ref 9). Utilization rate, sometimes known as duty-cycle or workload, is the percentage of time a controller is actively managing traffic.

Measurement and Modeling

This metric is unlikely to be measurable during field testing. Controllers do take steps to lighten the load on a sector whose traffic nears capacity, by issuing speed changes and vectors to approaching flights. If these measures do not bring traffic to acceptable levels, ARTCC supervisors will divert flights to neighboring sectors. These actions, though potentially identifiable, would be fairly difficult to spot in operating records. Also, the number of aircraft entering one air traffic management sector is dependent on the surrounding sectors and the flight plans of aircraft. These will be beyond the scope of testing. As a result, even if a controller could handle more aircraft, it is uncertain whether the air traffic management system could be made to route more aircraft to the affected sector.

Increased en-route sector capacity can be measured reliably during human-in-the-loop simulations to evaluate reduction in per-aircraft workload. This reduced workload should increase the number of aircraft a controller can manage at one time.

Prior to human-in-the-loop testing, the potential impact of AATT products can be estimated using models such as the Functional Analysis Model (FAM, ref 10) that utilizes a list of air traffic control event types, durations, sector configuration, and air traffic to simulate air traffic control workload and the utilization of controllers.

Increased en-route sector capacity can be used as an input to network models of the NAS such as LMINET or Approximate Network Delays (AND) to estimate impact on the overall NAS. The impact will be due to less rerouting around busy sectors and less delays for service in a sector. These, in turn, will reduce flight times and therefore costs. Higher fidelity modeling of controller duty cycles can

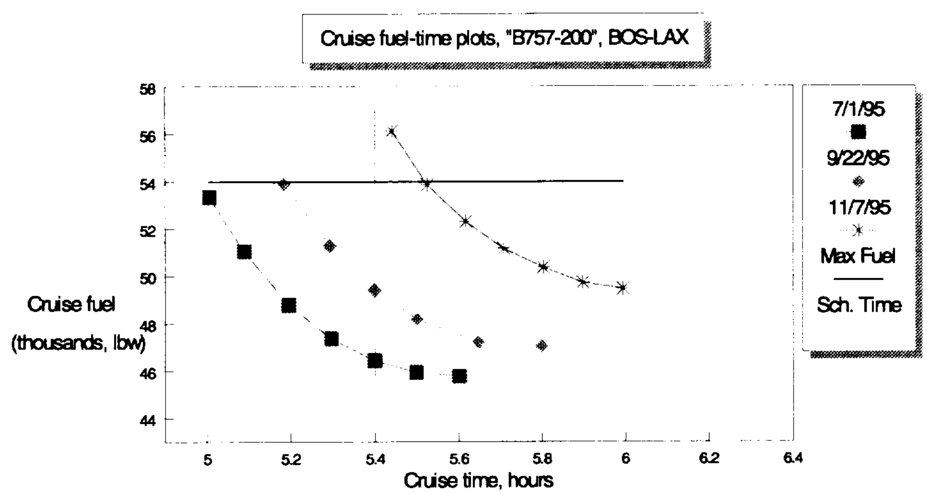
be accomplished using tools such as Reduced ATC Mathematical Simulator (RAMS) between initial benefits assessment and human-in-the-loop tests.

Block Time and Fuel

The degree to which the air traffic management system causes delays and imposes deviation from optimal flight tracks determines in part how much time it takes and how much fuel it takes to fly a given set of routes. These drive airline costs and efficiency that affect the cost of travel.

Block time and fuel are linked in that, within limits, the pilot generally can trade-off fuel and time, choosing to fly faster burning more fuel or slower burning less fuel. Figure 2-1 illustrates the possible fuel/time combinations for a Boeing 757-200 flying between Boston and Los Angeles for three different days. The different results show the influence of winds aloft.

Figure 2-1. Fuel-Time Possibilities for Certain Days



Definition

Block time is the amount of time from gate departure to gate arrival for a given flight.

Fuel is the amount of fuel consumed for the same flight.

In some ways, this paired metric is the common denominator among the AATT products. *All* AATT products influence the block time and fuel either directly by reducing the time it takes to accomplish a given phase of flight or reducing delay, or by allowing a more desirable flight path than would otherwise have been flown. The dollar value of these impacts can be estimated (see ref 11).

Measurement and Modeling

Data on block time and fuel for complete flights are available in either the ASQP (block time) or DOT's Form 41 financial and operations data (block time and fuel). Data for airborne phases of flight for a particular aircraft can be derived from ETMS data, although this is cumbersome. The FAA is developing a system to make these flight track data more useful.

Although block time and fuel for entire flights can be measured during field tests, it is challenging to determine changes in block time and fuel for flights versus what they would have been without the AATT technology. That is to say, a flight with a reduced flight time for the phase(s) of flight influenced by AATT products being tested might encounter other unrelated delays. Even so, the AATT program should attempt to compare flights under similar conditions with and without the AATT products.

It is easier to measure changes in the duration of particular phases of flight, such as taxi times or time to altitude, either from flight tracks or airline data and compute fuel burned during those phases of flight. The best data on these impacts could come from the airlines themselves. The airlines record information on block time and fuel by phase of flight, and they usually archive these data. At least one major airline has indicated its willingness to share these data with NASA. It is likely that other airlines would be willing to do so as well.

To extend test results and estimate systemic impacts of AATT products on block times and fuel, a series of models are required. A model of a network of flights, such as LMINET or Detailed Policy Analysis Tool (DPAT), necessary to generate expected delays with and without the AATT products. An aircraft physical performance model and track generator such as the ASAC Flight Segment Cost Model Mission Generator (ref 12) are needed to compute time and fuel savings for anticipated traffic with the reduced delays and more optimal routes.

ENABLE FREE FLIGHT

The nation's air traffic management philosophy is moving from the highly constrained system of yesterday toward one of minimal constraints on user flight paths. This new philosophy is known as *free flight*. Under free flight, airspace users will be allowed to choose their own routes, speeds, and altitudes to the extent that is consistent with safety. Moreover, when the air traffic management system needs to impose constraints on flights, airspace users will be consulted to the extent practical (for instance, an airline might be allowed to choose which flights incur necessary delays). The objective of free flight is to provide maximum flexibility to the airlines and other airspace users.

Many of the AATT products are being developed to support the transition to free flight. Unfortunately, there is no way to objectively measure the degree to which

AATT products will allow the FAA to relax restrictions 5 to 10 years in the future. Yet, the AATT program needs a metric to track its progress toward providing technologies to enable free flight.

The AATT products that will enable free flight include all those for en-route operations:

- CPTP
- AT/ST
- AERGA
- CAP
- E-CDTI
- APATH.

Additional products to facilitate collaboration between ATC and aircraft operators are planned but were not documented during the course of this study.

Definition

Enable free flight is a subjective evaluation of the AATT program's contribution toward developing technologies in support of free flight.

There are two distinct aspects to this metric. First, is the program doing the right things? This is an evaluation of the direction of the program. Second, did products that were tested accomplish what they were supposed to? This is an evaluation of the performance of the program.

Measurement

The simplest way to measure this metric is to seek out expert opinion. To be a supportable metric, these experts must be from outside the AATT program and not one of its contractors. Additionally, they must have knowledge of both the goals of free flight and the AATT program. These requirements greatly narrow the pool of people who can adequately evaluate the program.

Such a group does exist. It is NASA's Executive Steering Committee for air traffic management which is composed of various members of industry, government, and controllers. NASA should question this group, using the results to provide insights and to serve as the metric on this important issue. Figure 2-2 is a sample questionnaire that could be used for this purpose.

Figure 2-2. Enable Free Flight Questionnaire

Sample Questionnaire

1. *How familiar are you with the free flight concept?*

1 2 3 4 5
Not Familiar Very Familiar

2. *To what extent do you support free flight?*

1 2 3 4 5
Don't support Strongly Support
Why?

3. *Do you believe the AATT program's decision support tools (DSTs) will help enable free flight?*

Yes No

4. *How important are the AATT DSTs to implementing free flight in the next 3-5 years?*

1 2 3 4 5
Will have little impact Can't implement without them

Beyond 5 years?

1 2 3 4 5
Will have little impact Can't implement without them

5. *Is the AATT program developing the right technologies to support free flight?*

1 2 3 4 5
Wrong Tools Some but not all Right Tools

6. *Is the AATT developing technologies rapidly enough to support free flight implementation?*

1 2 3 4 5
Much too slowly Tools are ready long before needed

7. *The ____ DST was tested this year. Do test results demonstrate live up to expectations?*

1 2 3 4 5
No Some Far exceed

Please comment on the reverse.

OTHER METRICS CONSIDERED

In arriving at these four program-level metrics, we considered a variety of other metrics that are either currently in use or proposed. Many of those were very detailed, such as controller situational awareness or number of flights deviating from filed plans. Others—such as reduced emissions or objective measures of flexibility, which will be likely outcomes of AATT technologies once fully implemented—are not the focus of the program.

In general, the measures fell into seven categories:

- Capacity
- Flexibility
- Efficiency
- Predictability
- Safety
- Environment
- Delay.

The metrics we recommend address the first three of these. Capacity is measured in the airport/terminal area and en-route sector. Block time and fuel measure efficiency. Flexibility is measured by enabling free flight.

Greater predictability and reduced emissions are likely eventual outcomes of the AATT program resulting from reduced flight times, added capacity, and reduced fuel consumption.

No AATT product will be implemented if it would reduce safety. In fact, by allowing less congestion, reducing potential conflicts, and enhancing the ability of controllers and air crew to deal with more air traffic, every product in the AATT program will enhance safety. Again, increasing safety is not a primary goal of the program; however, maintaining the current level of safety, at a minimum, is a program constraint.

Delay is difficult to measure since some degree of delay is built into schedules and not all delays are reported by either the airlines or FAA. The Department of Transportation allows airlines to call arrivals that are less than 15 minutes late "on time." When controllers vector or slow aircraft without putting them into holding patterns, the FAA does not report any delay. Delays also can be caused by other

factors, such as headwinds that are unrelated to air traffic management. Reductions in block time are an indicator of reductions in delay without any of these complications.

Chapter 3

AATT Program's Potential Impacts

Airport Peak Capacity

Airport congestion is the biggest single cause of delay in the NAS (ref 10). The AATT program will have its greatest impact at the airports and in the terminal area. A variety of AATT products address airport and terminal area congestion.

Two of those products, the Passive Final Approach Spacing Tool (PFAST) and the Traffic Management Advisor (TMA) already have been tested and are currently operational at Dallas-Fort Worth International Airport. Test results were highly successful, increasing peak runway arrival capacity by about 13 percent (ref 13). Those tools advise controllers about expected arrivals, metering traffic into the terminal area, sequencing, and runway assignment.

Three other tools will improve airport capacity. Active FAST is the follow-on to PFAST. It will provide flight track recommendations for individual aircraft in addition to planning sequence. Expedite Departure Path (EDP) will assist in managing departure traffic. However, most of its benefits will involve improved flight profile (see the Block Time and Fuel section below) rather than in increased capacity. The SMA will improve ground operations, reducing unused runway capacity because aircraft cannot get to or from a crowded runway.

To evaluate AATT's potential impact on airport capacity, we primarily focused on AFAST, accepting the PFAST/TMA improvements as given[1]. We utilized the Airport Capacity Models to accomplish the analysis. Lee, et al. (ref 11) provides details on this analysis, which is summarized below.

To account for PFAST/TMA improvements, we increased individual runway capacities by about 5 percent in peak arrival rate due to sequencing and peak departure rate by about 4 percent reflecting less arriving aircraft being diverted to departure runways. The remaining 8 percent improvement in arrival rates reflects a better balance among arrival runways, a factor already assumed by the model.

To model AFAST, we created new arrival/departure Pareto frontiers in the airport capacity models (refs 6, 7, and 8) by adjusting input parameters to the models. These frontiers show the capacity of a runway given a mix of arrivals and departures.

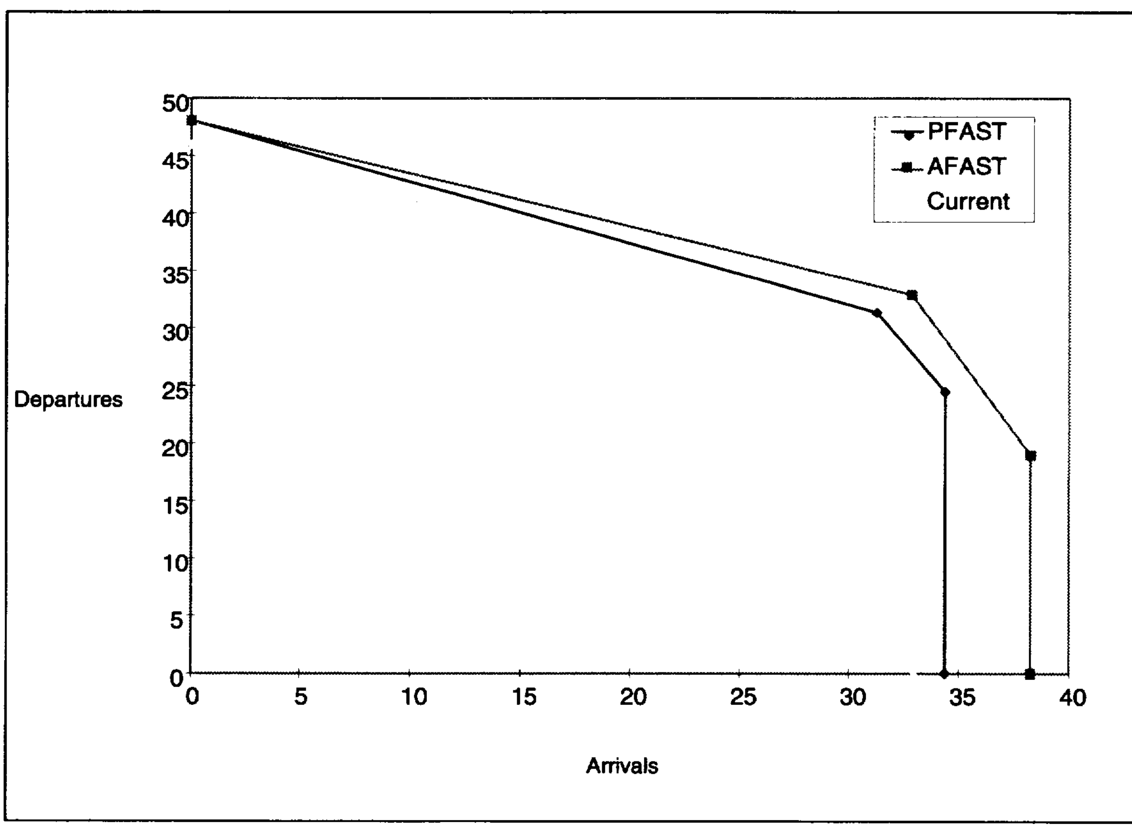
[1] We assume similar benefits at other parallel runway airports.

AFAST should result in "tighter means and smaller standard deviations of in-trail separations on final approach, ... and shorter common approach lengths" (ref 1). Additionally, we assume that AFAST will provide controllers more accurate position and speed information. Specifically we model AFAST by (ref 11):

- reduction in position uncertainty from 0.25 nautical miles (500 yards) to 100 feet;
- reduction in the standard deviations of approach speeds from 5 knots to 2.5 knots;
- reduction in the standard deviation of wind variation from 7 knots to 5 knots, reflecting AFAST's reduction in approach profile variability; and
- reduction of common path length from 6 nautical miles to 5 nautical miles.

The new pareto frontiers describing runway capacities for instrument landing conditions category 1 are illustrated in Figure 3-1. Similar frontiers were created for other weather conditions. The single runway arrival capacity improvements under visual and instrument flight rules combing AFAST and PFAST are on the order of 16 percent to 20 percent.

Figure 3-1. Airport Departure/Arrival Capacity Pareto Frontiers



To determine AATT's potential impact, this improvement must be combined with the observed 8 percent improvement due to runway load balancing yields. The combined impact of TMA, PFAST, and AFAST is an improvement of 24 percent to 28 percent in peak airport capacity.

These tools focus on arrivals. AATT tools such as EDP may improve departure capacity, primarily by sequencing aircraft. While arrival rushes and departure rushes tend not to coincide, with arrival rushes having more impact on the airport and the NAS, some benefit in total airport capacity is likely to occur due to these tools. Other AATT tools that will impact airport capacity are in the early stages of concept development or are planned for the future.

It is likely that AATT will achieve an improvement in airport peak capacity of about 30 percent under most weather conditions. Additional improvements are possible but will be more difficult to obtain.

We recommend that the AATT program establish the following:

- *Program objective.* Increase airport peak capacity by 30 percent.
- *Stretch Goal.* Increase airport peak capacity by 40 percent.

The stretch goal reflects an aggressive effort by the program to further improve arrival and departure capacities.

EN-ROUTE SECTOR CAPACITY

The AATT products that will increase en-route sector capacity will do so primarily by reducing the number of potential conflicts (aircraft on flight paths that could put them too close to each other) and the workload to resolve each conflict. These two factors reduce the controller's average workload per aircraft, thereby offering the opportunity to increase the number of aircraft in any one sector. The tools that will accomplish this are as follows:

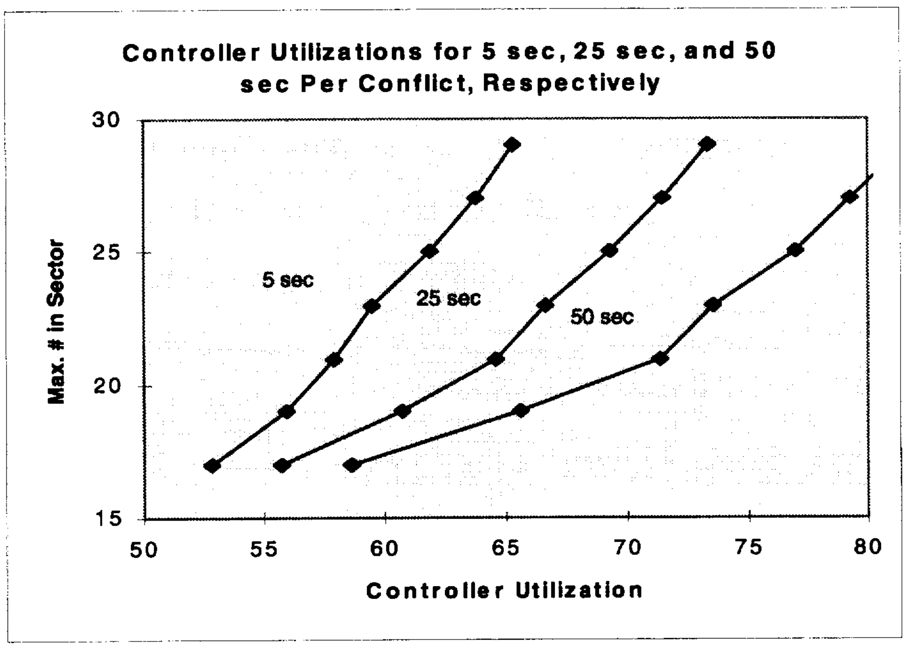
- CPTP
- AT/ST
- AERGA
- E-CDTI.

To estimate the potential increase in sector capacity, we used the Aircraft Air Traffic Management Functional Analysis Model (FAM) to simulate air traffic with conflicts but with varying time to resolve each conflict. FAM is a low-fidelity model that simulates controller and air crew workload based on a series of

events, each taking a certain amount of time. For more detail on FAM, see reference 9.

Following a review of the literature and discussions with controllers, it was determined that all actions associated with resolving a potential conflict take on average, 50 seconds (refs 9 and 14). We postulated that this could be reduced by half, to 25 seconds per conflict resolution. We ran these two cases along with a best imaginable case where each conflict took only 5 seconds to resolve. The results are shown in Figure 3-2. Note, all other workload is assumed to be unchanged. For more detail on this analysis see reference 11.

Figure 3-2. Impact on Controller Workload of Reduced Time to Resolve Conflicts



As can be seen from the figure, current workload (the 50 second per conflict line) equates with a controller utilization rate of 62.5 percent at 18 aircraft per sector.

To estimate AATT's potential impact, we held utilization constant in the range of 60 percent to 65 percent and measured the resulting impact on aircraft per sector. At 60 percent utilization, the aircraft per sector increases from 17 to 18; at 65 percent, it increases from 18.5 to 21.5. This equates to a 6 percent to 16 percent increase. Given the fidelity of the model, and to create achievable yet aggressive goals, we recommend the AATT program establish the following:

- *Program objective.* Increase en-route sector capacity by 10 percent.
- *Stretch goal.* Increase en-route sector capacity by 20 percent.

BLOCK TIME AND FUEL

Block time and fuel are measures of the efficiency of the NAS. All AATT products will impact time and fuel, either directly, such as EDP by reducing time to climb, or indirectly, such as AFAST by increasing airport capacity and, reducing delay.

Reducing block time and fuel will have huge impacts. The airlines will save hundreds of millions of dollars in direct operating costs for every percentage reduction in block time. They also will be able to schedule their fleets more effectively. The air traffic control system will have to handle less aircraft at any one time because flights are in the air or on the taxiways for less time. The traveling public will save time and, presumably, dollars as the airlines pass some of their reduced costs on in the form of lower fares.

To estimate AATT's potential impact on block time and fuel, we considered two factors, inefficient flight trajectories and delays. We discuss each below. Table 3-1 shows recent and anticipated year 2005 average flight characteristics. We used the 2005 projections in our analysis of AATT impacts.

Table 3-1. 1994 and Predicted 2005 Flight Characteristics[a]

Flight characteristics	1994	2005
Average stage length	681	710
Block time	1.92	1.99
Fuel	2,130	2,192

[a]1994 baseline data and FAA trip length increase projections (ref 12) were used to compute new average stage lengths. We assumed additional distance would occur at cruise (450 knots and 16 gal./min.)

INEFFICIENT FLIGHT PROFILES

The air traffic management system can contribute to inefficient flight trajectories during all phases of airborne flight by restricting altitude, speed, or course flown. For our analysis, we consider the following phases of flight:

- Climb
- Exit from or entrance to the terminal area
- Cruise
- Descent.

Each of these is discussed in a subsection below.

Climb

By restricting how rapidly an aircraft can climb to cruise altitude where it operates most efficiently, the air traffic management system causes an aircraft to burn additional fuel. This penalty is estimated at 300 pounds in the most congested terminal areas (or about 50 gallons) per flight (ref 11). This equates to 2 percent of the fuel burn on an average flight in 2005, with 38 percent of flights being impacted.[2] The total impact is an 0.8 percent reduction in fuel consumed per flight in the NAS. We estimate that EDP could potentially save between half and three-quarters of this amount, equating to 0.4 percent to 0.6 percent. We anticipate minimal impact on total flight times since faster climbs mean additional distance to be traveled at cruise.

Exit from or Entrance to the Terminal Area

Standard Instrument Departure (SID) and Standard Terminal Arrival (STAR) procedures cause aircraft exiting or entering terminal areas to fly specific paths over specific points frequently hundreds of miles from the departure or arrival airport. One such route from Atlanta terminates at Memphis nearly 400 miles distant. The effect of this is to cause aircraft to fly additional distance.

AATT products that enable better management of traffic in congested terminal areas have the potential to enable the FAA to bring these points closer to the airports, thereby reducing the extra distance traveled. These tools are EDP, CPTP, AT/ST (primarily ST), AERGA, E-CDTI, and APATH.

That extra distance is a function of the distance traveled along the STAR or SID and the location of the STAR or SID. To estimate the magnitude of the diversion, we made the simplifying assumption that the entire STAR or SID path to its endpoint was in a relatively straight line. (Some of this is traveled toward the destination but some is a diversion). We then calculated the extra distance traveled as a function of angular diversion, distance from the airport to the endpoint and distance of the ultimate destination or original origin to the endpoint. The results are shown in Table 3-2.

We estimate the additional distance traveled at between 5 and 15 miles per flight for both SID and STAR or 10 to 30 miles overall, adding 1.3 to 3.5 minutes to an average flight. During this time, the aircraft burns 19 to 55 gallons of fuel. Bringing the endpoints in to about 50 miles would eliminate 80 percent of this in almost all cases. Resulting savings would range from 0.8 percent to 2.4 percent of block time and 0.7 percent to 2.1 percent of fuel.

[2] Based on the FAA's *2005 Terminal Area Forecast* (ref 15) for 15 of the busiest airports.

Table 3-2. Extra Miles Traveled on SID/STAR as a Function of Angle,SID/STAR Distance, and Distance to Ultimate Destination/Origin

Degrees off course	SID/STAR distance	Destination/origin distance				
		750	1,000	1,500	2,000	2,500
		Extra distance travelled				
5	100	0.4	0.4	0.4	0.4	0.4
10	100	1.8	1.7	1.6	1.6	1.6
15	100	3.9	3.8	3.6	3.6	3.5
5	200	1.0	1.0	0.9	0.8	0.8
10	200	4.1	3.8	3.5	3.4	3.3
15	200	9.2	8.5	7.8	7.6	7.4
5	300	N/A	1.6	1.4	1.3	1.3
10	300	N/A	6.5	5.7	5.4	5.2
15	300	N/A	14.5	12.7	11.9	11.6

Cruise

By restricting where an aircraft flies, at what altitudes, and at what speeds, the air traffic management system imposes inefficiencies on flights over the best possible routing. In comparing as-flown ETMS data for a variety of flights in 1996 with optimal (wind route) flights for those same days, the estimated time savings is 0 percent to 0.7 percent per flight (0 to 2 minutes) with an average time savings of 0.3 percent (ref 11). An average jet would save about 0.1 percent of its fuel during that period.

These results differ from our earlier study, which compared IFR preferred routes with optimal routes. The ETMS data we examined show that flights usually fly much more efficient paths than those routes.

A variety of AATT tools, including CPTP, AT/ST, AERGA, and E-CDTI, are designed to facilitate free flight with the implicit assumption that this will enable more efficient routing. We estimate these tools could eliminate 50 percent to 75 percent of these inefficiencies, some of which require other technologies or would require policy changes unrelated to AATT. With rounding, that equates to a 0.2 percent savings in block time and a 0.1 percent savings in fuel.

Descent

By forcing aircraft to descend early and usually reduce speed as well, the air traffic management system causes the aircraft to burn more fuel and take more time. Flights at some congested airports impacting 30 percent of flights spend as much as 7 to 9 minutes longer below 11,000 feet than optimal flight paths would otherwise indicate. Since speeds at these altitudes are roughly one-half the normal

cruise speeds to control noise and restrict flow, roughly four minutes are added to each flight at those airports. This equates to 3.4 percent for those flights or 1.0 percent on the NAS overall. This adds 0.7 percent per flight in additional fuel consumption.

We estimate that TMA, PFAST, AFAST, AT/ST, and AERGA could reduce this time by between one-third and two-thirds, resulting in a 0.3 percent to 0.7 percent block time reduction and 0.2 percent to 0.5 percent savings in fuel.

DELAYS

We considered two categories of delay in establishing AATT's potential impact on block time and fuel. The first of these is airborne delays; the second is taxi delays.

Airborne Delays

By increasing capacity at airports and en-route sectors (see above), AATT will help reduce airborne delays. To estimate the size of this impact, we used our estimated capacity improvements in those areas as input to LMINET and compared the results for projected 2005 traffic against results of a base case without the improvements as shown in Table 3-3.

Table 3-3. Expected Airborne Delays

AATT status	Average airborne delay (minutes)	Fuel burned during airborne delay (gallons)	Time savings (minutes and percent)	Fuel savings (gallons and percent)
2005 without AATT	0.92	16.2	NA	NA
2005 with AATT	0.64	11.2	0.28 (0.2%)	5.0 (0.2%)

Note: Since this is averaged across all flights, many of which encounter no airborne delay, the average opportunity is small. In addition, most predictable delays are assumed to occur prior to takeoff.

The total expected delay is 0.9 percent of block time and 0.9 percent of fuel. If AATT products can help eliminate between one-third and two-thirds of this amount, the potential savings range from 0.3 percent to 0.6 percent for both.

Taxi Delays

AATT tools will help decrease both taxi-out and taxi-in delays. Table 3-4 highlights taxi-out delays at major airports. Those delays are expected to grow as traffic at busy airports increases.

Most taxi-out delays are associated with departure queues. In many cases, these queues arise from the airlines scheduling many flights to depart in a brief period, far exceeding airport capacity. EDP will increase departure capacity mitigating the problem somewhat.

Table 3-4. January 1993 Taxi-Out Delays at Major U.S. Airports

Airport name		Average delay (minutes)	Standard deviation delay (minutes)	Departures
ATL	Hartsfield International, GA	6.1	7.5	266,830
EWR	Newark Airport, NJ	5.7	8.0	135,724
JFK	J. F. Kennedy International Airport, NY	5.4	7.4	75,604
DFW	Dallas/Ft. Worth In, TX	5.2	7.3	349,228
MIA	Miami International Airport, FL	5.1	7.1	110,702
LGA	La Guardia Airport, NY	5.1	6.7	135,848
DEN	Stapleton International, Denver, CO	4.7	7.1	177,482
MSP	St. Paul International, MN	4.2	7.4	131,468
SLC	Salt Lake City, UT	4.1	7.0	82,173
DTW	Wayne Co. Airport, MI	3.7	6.2	141,296
LAX	Los Angeles International, CA	3.2	5.7	185,864
SFO	San Francisco International, CA	3.2	2.0	150,105
BOS	Logan International Airport, MA	3.1	5.4	154,841
DCA	National Airport, DC	3.1	5.4	97,121
ORD	O'Hare International Airport, IL	3.0	5.6	378,073
BNA	Nashville, TN	2.9	4.7	64,413
CVG	Cincinnati, OH	2.8	4.8	73,529
PHX	Sky Harbor International, AZ	2.7	4.4	143,609
IAD	Dulles International Airport, DC	2.7	5.3	44,676
PHL	Philadelphia International, PA	2.7	5.1	108,935

Source: DOT Form 100 data.

To estimate the impact of AATT capacity increases on future departure delays, we used the runway capacity models and LMINET to predict those delays in 2005 with and without various improvements (ref 11). The results are shown in Table 3-5.

Table 3-5. Impact of AATT Capacity Increases on Taxi-out Delays

AATT status	Average minutes taxi-out delay	Fuel burned during taxi-out delay	Time savings (hours [%])	Fuel savings (gallons [%])
2005 without AATT	1.72	10.4	NA	NA
2005 with AATT	1.52	9.2	0.20 (0.2%)	1.2 (0.1%)

The Advanced Surface Movement Advisor, SMA-2, will further reduce taxi-out delays by providing the opportunity to better sequence departing aircraft. By grouping large aircraft together, an additional 1 to 2 minutes of time could be saved on roughly half of all flights. This equates to 0.4 percent to 0.8 percent of block time during which 0.1 percent to 0.2 percent of total fuel would be saved.

Combined, these two impacts yield a time savings of 0.6 percent to 1.0 percent of block time and 0.2 percent to 0.3 percent of block fuel.

AATT'S POTENTIAL IMPACT ON BLOCK TIME AND FUEL

The total block time and fuel spent flying inefficient routes and during delays is shown in Table 3-6. It also shows the estimated AATT impacts. The cumulative effect of the AATT program could be a 2 percent to 5 percent reduction in block time and a 2 percent to 4 percent reduction in fuel as shown in Table 3-6. These numbers lead to our recommendations:

- *Program objective.* Reduce block time and fuel by 2 percent.
- *Stretch goal.* Reduce block time by 5 percent and fuel by 4 percent.

Table 3-6. AATT's Potential Impact on Block Time and Fuel

Action	Block time reduction lower bound (%)	Block time reduction upper bound (%)	Fuel reduction lower bound (%)	Fuel reduction upper bound (%)
Climb	0	0	0.4	0.6
Exit/entry of terminal area	0.8	2.4	0.7	2.1
Cruise	0.2	0.2	0.1	0.1
Descent	0.3	0.7	0.2	0.5
Airborne delay	0.3	0.6	0.3	0.6
Taxi delays	0.6	1.0	0.2	0.3
Total	2.2	4.9	1.9	4.2

ENABLE FREE FLIGHT

It is not yet possible to establish a goal for this metric other than to provide free-flight enabling technologies. Initial evaluation of the program by its Executive Steering Committee should occur in early 1998. After that baseline is established, the program can set goals based on the scoring. The goal for this metric is still likely to be *maintain or improve*, rather than manifestation of a quantitative objective for this subjective measure.

Chapter 4
Using the Metrics: Recommendations

The four metrics—airport peak capacity, en-route sector capacity, block time and fuel, and enable free flight—provide full coverage for major AATT objectives and all AATT products. They should be employed at both the program and product levels of the organization.

Using the Metrics at the Program Level

At the program level, the metrics serve four primary purposes. They should be used to

- establish program goals,
- relate products to each other,
- track program progress, and
- communicate with NAS stakeholders.

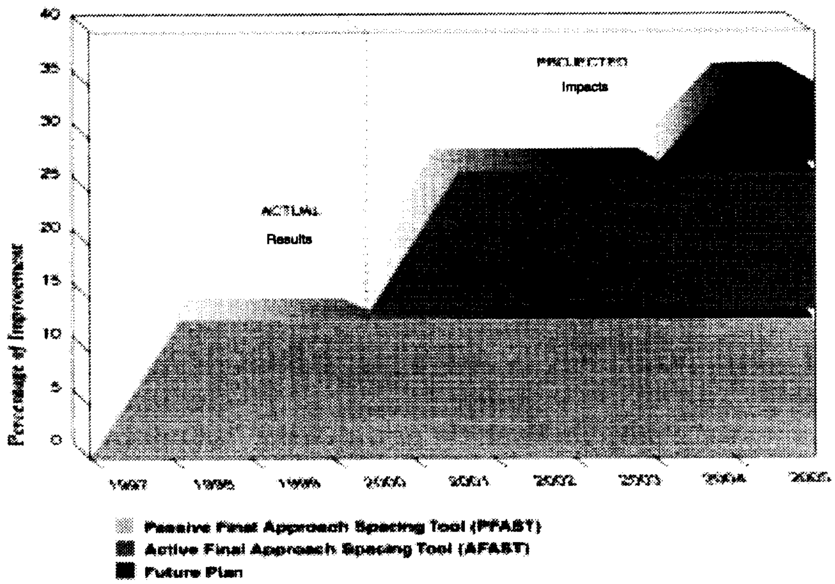
Prior to this metrics development activity, the AATT program has not had a set of program metrics or goals. The metrics and goals developed in this activity provide the first step in providing program management and various oversight bodies with quantified measures of the potential performance benefits of this program.

In the previous chapter, we provided a rationale to justify specific goals for the three objective metrics. This should serve as the basis for discussions within NASA that should result in specific program goals.

Once goals have been established, the goals associated with individual products and the products' individual contributions can be assessed. The next logical step is for the program to develop goals for individual products. This enables program managers to set priorities and devote management attention where most needed.

The AATT program should use these metrics to track both its accomplishments and expected future progress. Figure 4-1 is an example of how this might be displayed graphically.

Figure 4-1. Tracking Metrics



Individual product contributions are not independent. The results of an early project serve as the new baseline for follow-on projects. To maintain the integrity of its projected accomplishments, the program office should conduct analysis to model the cumulative impacts of multiple products, especially if product tests are to be conducted at different sites.

Tracking metrics should be event-driven. That is to say, individual products should not require a detailed effort to estimate their contributions based on a calendar date. Rather, their contributions should be updated when they reach a milestone, such as testing, or, as they change, their concepts should be refined to change significant details.

The program manager should be able to say "PFAST and TMA improved airport peak capacity by 13 percent; AFAST should improve it by another 16 percent to 20 percent; and by the time the program is over, we will have demonstrated that the technologies improve capacity by 30 percent to 40 percent." The program and product goals, status, and plans identified in the study serve as the basis for effective communications with NAS stakeholders.

USING THE METRICS AT THE PRODUCT LEVEL

The metrics and goals we have introduced for the AATT program are the basis for individual product metrics, including but not limited to the four discussed. As part of a structured systems engineering process and formal metrics programs, the AATT program should develop analysis plans for each of its products. These

plans may be stand alone, although they may be included in other development documentation.

Currently, most individual AATT products do not have specific goals that they are trying to achieve. Furthermore, some products have begun testing without data collection or without plans on how they would analyze the data to determine how successful the product was.

Product analysis plans should include the following sections:

- ***Goals.*** This section should address fundamental questions: What program goals is the product contributing to? What is the expected impact of the product (e.g., reduce time to climb [a phase of flight] by 15 percent.) AATT products have broad objectives in terms of what they hope to achieve. These need to become more specific during concept exploration.

- ***Physical Parameters.*** What physical parameters will the product impact? In modeling AFAST, for example, we assumed reduction in various uncertainties and in common path length. Once each product knows its goals, it should analyze how it intends to achieve them.

- ***Other Important Factors.*** In addition to the parameters changed to achieve product goals, each product must measure its impact on other factors such as safety (e.g., spacing and alerts) and acceptability to users. These must be defined as part of the measurement planning process.

- ***Baseline Data.*** In order to assess product impacts, baseline data for sites or situations equivalent to expected test conditions must be collected, preferably early in concept exploration and again as close to testing as possible. This is not the same as collecting general or NAS overall baselines. Specific baseline data must be comparable and matchable to test data. How the product team plans to collect baseline data needs to be part of the plan.

- ***Data Sources.*** How will data on program goals, key parameters, and other important factors be collected? What existing data sources will be used? What observers will be necessary? What logs or airline data are needed? Will controllers, air crew, or others be asked to evaluate the technology or the test? Do any new data sources need to be established? These questions need to be addressed so that all necessary data are collected.

- ***Tests.*** How many tests will be performed? Where? What specific conditions (e.g., flight rules, traffic, etc.) will be sampled? Who will participate? At what points in the development cycle? What constitutes success? Specific test plans should be developed in advance of each test.

- ***Models.*** What models are necessary to calculate the impact of parameters on program goals early in development or the extend test results to the NAS? Do they exist or do they need to be developed? Have they been or will they be approved by the program office?

- ***Analysis.*** What analysis of test data needs to be performed to assess the success, safety, and acceptability of the product? Will the baseline and test data be sufficient to perform the analysis? When will the analysis team be formed, and who will it be? How much time and resources are necessary for the analysis?

- ***Roll-up.*** How will product planned impacts and actual test results be combined with related products for roll-up into program metrics? Although performed at the AATT program level, the products need to ensure their compatibility with program-level analyses.

Naturally, analysis plans will become more specific as products progress through the development cycle. In the earliest stages of development, these plans will be rough, consisting mainly of broad goals, baseline data, and key parameters. The plans should rapidly become more detailed as concepts are explored. They should be quite detailed long before demonstration and test.

Chapter 5

Summary, Conclusions, and Recommendations

SUMMARY

LMI's task was to identify metrics and success criteria for the overall AATT program. We have identified four metrics that provide full coverage for all AATT products and implicit program goals. They are:

- ***Airport peak capacity.*** In terms of operations per hour as measured in a 15-minute interval when demand exceeds capacity. This metric applies to airport terminal area operations. This metric needs to be applied to all weather conditions prevalent at an airport.
- ***En-route sector capacity.*** In terms of the number of aircraft a controller can safely handle at one time. This metric applies to en-route operations.
- ***Block time and fuel.*** Two to five percent and two to four percent, respectively, in terms of the time and fuel necessary to fly a set of routes with particular aircraft under similar conditions. This metric applies to airport terminal area, en-route, and ground operations. That is to say, it applies to all AATT products.
- ***Enable free flight.*** Involves expert evaluation of the AATT program's progress toward providing free flight-enabling technologies. This metric applies to en-route operations.

These metrics provide measures of NAS capacity, efficiency, and flexibility. Indirectly, block time provides a measure of NAS delay; variance in block time provides a measure of NAS predictability. The AATT program also will have a positive impact on NAS safety and reduce emissions to the environment, but these are not the primary focus of the program.

The AATT program's potential impact on the NAS has been estimated for the three objective metrics with an achievable program objective and a more aggressive stretch goal for each:

- Increase airport peak capacity by 30 percent to 40 percent.
- Increase en-route sector capacity by 10 percent to 20 percent.
- Reduce block time by 2 percent to 5 percent and block fuel by 2 percent to 4 percent.

Each AATT product contributes to one or more program metrics either directly or indirectly by improving overall performance of the NAS as shown in Table 5-1.

Table 5-1. Key metrics for AATT products

	Direct impact	Indirect impact
Terminal Area		
TMA	Airport peak capacity	Block time/fuel
P-FAST	Airport peak capacity	Block time/fuel
A-FAST	Airport peak capacity	Block time/fuel; enable free flight
EDP	Airport peak capacity; block time/fuel	Enable free flight
En-route		
CPTP	En-route sector peak capacity	Block time/fuel; enable free flight
AT/ST	En-route sector peak capacity	Block time/fuel; enable free flight
AERGA	Airport capacity; en-route sector peak capacity; enable free flight	Block time/fuel
CAP	Enable free flight	Block time/fuel
E-CDTI	En-route sector peak capacity	Block time/fuel; enable free flight
APATH	Enable free flight	Block time/fuel
Ground		
SMA-1	Block time/fuel	N/A
SMA-2	Block time/fuel	Enable free flight

Conclusions and Recommendations

We have provided the AATT program with four unifying metrics that can be used to establish program goals, relate individual projects to each other and prioritize them, and communicate with NAS stakeholders. The AATT program should adopt these metrics.

The program should then set goals for these metrics. We have estimated the program's likely and potential impacts to support that process. The AATT program contributes to, but will not achieve NASA's global civil aviation goals.

The next logical steps are to begin a metrics tracking process at the program level and develop product goals and analyses plans. At the program level, only a modest level of effort is required to set goals and track progress. At the product level, a more significant effort is required to set goals[1] and develop metrics and analysis plans appropriate for the product. These efforts are necessary if AATT is to succeed in its transition from a collection of independent projects to a single focused program.

[1] A note of caution: AATT is a research and development program. As concepts are explored and knowledge gained, goals for the program and its products may need to be revisited.

During the next year, NASA should shift its metrics focus from the program level to the products.

By taking these steps, the AATT program will be able to track and communicate program objectives and status and will be better able to compare AATT products, their individual status, and their priority relative to each other.

References

[1] Mark Ballin, et al., *Summary Overview and Status of AATT Program Development Activities*, NASA Ames Research Center, Moffett Field, CA, draft dated 7 August 1997.

[2] AATT Program Office, *ATM Concept Definition,* Version 1.0, NASA Ames Research Center, Moffett Field, CA, 21 October 1997.

[3] RTCA, Inc., *Final Report of the RTCA Task Force 3 Free Flight Implementation*, RTCA, Washington, DC, 26 October 1995.

[4] *Aeronautics & Space Transportation Technology: Three Pillars for Success*, NASA, Washington, DC, March 1997.

[5] LMI Report NS501T1, *Technical and Economic Analysis of Air Transportation Management Issues Related to Free Flight,* David Lee, et. al., February 1997.

[6] David Lee, et al., *Estimating the Effects of the Terminal Area Productivity Program* , NASA CR-201682, April 1997.

[7] Robert Hemm, et al., *Preliminary Cost-Benefit Estimates of the Terminal Area Productivity Program Technologies,* NASA Contractor Report, forthcoming.

[8] David Lee, et al., *The ASAC Airport Capacity and Delay Models*, NASA Contractor Report, forthcoming.

[9] A. Robertson, et. al. *Validation of Air Traffic Controller Workload Models,* US Department of Transportation, Transportation Systems Center, Cambridge, Ma., Report FAA-RD-79-83, September 1979.

[10] Melvin Etheridge, et. al., *Aircraft/Air Traffic Management Functional Analysis Model Version 2.0, User's Guide*, NASA Contractor Report, forthcoming.

[11] David Lee, et al., *A Method for Making Cross-Comparable Estimates of the Benefits of Decision Support Technologies for Air Traffic Management,* NASA Contractor Report, forthcoming.

[12] Bruce Kaplan, et al., *The ASAC Flight Segment and Network Cost Models* , NASA CR-201679, April 1997.

[13] J. T. Davis, et al., *Operational Test Results of the Passive Final Approach Spacing Tool,* 8th IFAC Symposium on Transportation Systems, Chiania, Greece, June 1997

[14] Interview between David Lee et al. Of LMI and Mr. Don Bringmann of the FAA's Command Center, Herndon, VA, 10 September 1997.

[15] FAA Office of Aviation Policy, *FAA Aviation Forecasts, Fiscal Years 1996-2007*, FAA-APO-96-1, Washington, DC, March 1996.

Appendix A
Abbreviations

AATT	Advanced Air Transportation Technologies
ACARS	ARINC Communications Addressing and Reporting System
AERGA	Advanced En-route Ground Automation
AFAST	Active Final Approach Spacing Tool
AND	Approximate Network Delays
APATH	Airborne Integrated Route Planner for Avoiding Traffic and Hazard
ARTCC	Air Route Traffic Control Center
ASAC	Aviation Systems Analysis Capability
ASQP	Airline Service and Quality Performance
AT	Airspace Tool
ATC	Air Traffic Control
CAP	Collaborative Arrival Planning
CPTP	Conflict Probe/Trial Planning Tool
CTAS	Center-TRACON Automation System
DPAT	Detail Policy Analysis Tool
DST	Daylight Saving Time
EDP	Expedite Departure Path
ETMS	Enhanced Traffic Management System
FAA	Federal Aeronautics Administration
FAM	Functional Analysis Model
FAST	Final Approach Spacing Tool
IFR	Instrument Flight Rules
LMINET	A queuing network model of the U. S. national airspace system
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
PASSUR	Passive Surveillance Radar

PFAST	Passive Final Approach Spacing Tool
RAMS	Reorganized ATC Mathematical Simulator
SID	Standard Instrument Departure
SMA	Surface Movement Advisor
ST	Sector Tool
STAR	Standard Terminal Arrival Route
TMA	Traffic Management Advisor

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503			
1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE May 1998	3. REPORT TYPE AND DATES COVERED Contractor Report	
4. TITLE AND SUBTITLE Key Metrics and Goals for NASA's Advanced Air Transportation Technologies Program			5. FUNDING NUMBERS C NAS2-14361 Task 97-09 WU 538-08-11-01
6. AUTHOR(S) Bruce Kaplan and David Lee			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Logistics Management Institute 2000 Corporate Ridge McLean, VA 22102-7805			8. PERFORMING ORGANIZATION REPORT NUMBER NS709S1
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Langley Research Center Hampton, VA 23681-0001			10. SPONSORING / MONITORING AGENCY REPORT NUMBER NASA/CR-1998-207678
11. SUPPLEMENTARY NOTES Langley Technical Monitor: Robert E. Yackovetsky Final Report			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 01 Distribution: Nonstandard Availibility: NASA CASI (301) 621-0390			12b. DISTRIBUTION CODE
13. ABSTRACT *(Maximum 200 words)* NASA's Advanced Air Transportation Technologies (AATT) program is developing a set of decision support tools to aid air traffic service providers, pilots, and airline operations centers in improving operations of the National Airspace System (NAS). NASA needs a set of unifying metrics to tie these efforts together, which it can use to track the progress of the AATT program and communicate program objectives and status within NASA and to stakeholders in the NAS. This report documents the results of our efforts and the four unifying metrics we recommend for the AATT program. They are: airport peak capacity, en-route sector capacity, block time and fuel, and free flight-enabling.			
14. SUBJECT TERMS Aviation Goals, Aviation Metrics, Capacity, Delay, Free flight			15. NUMBER OF PAGES 43 16. PRICE CODE A03
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102